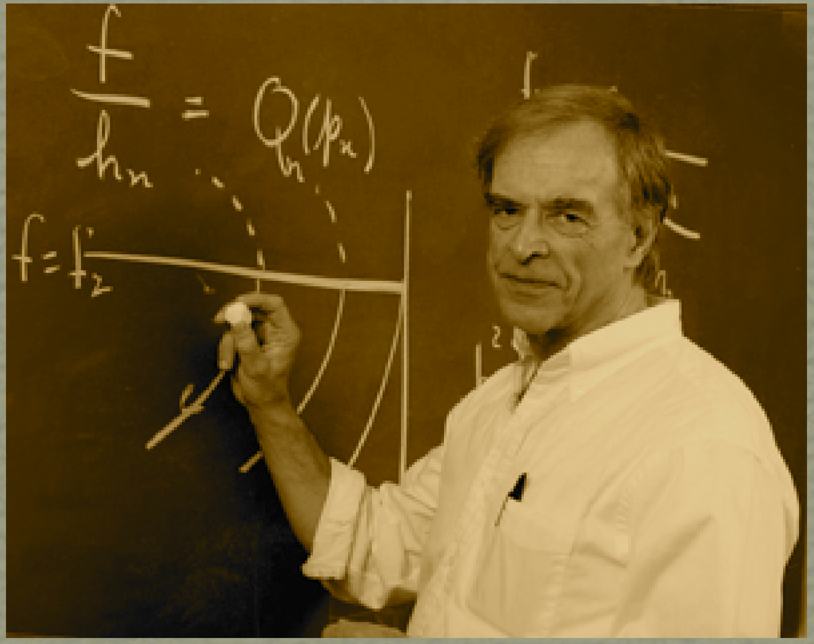
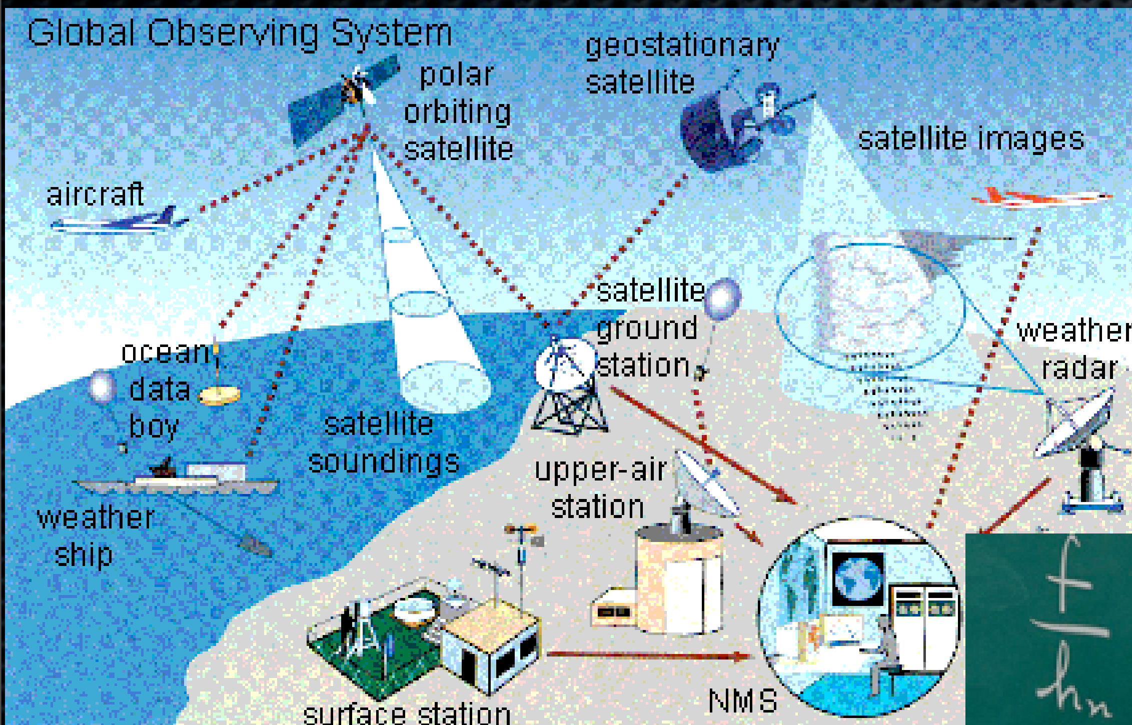
# Symposium to Honor
# Joe Pedlosky

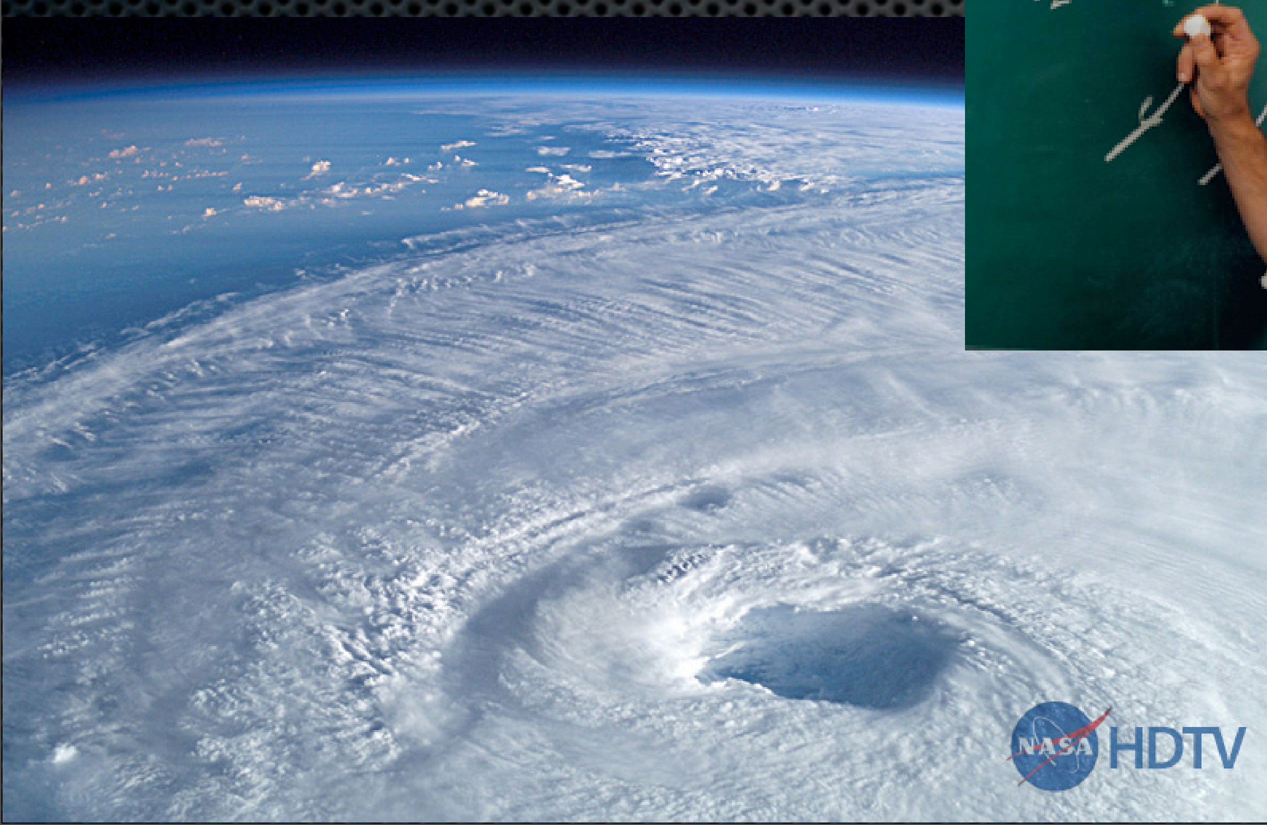


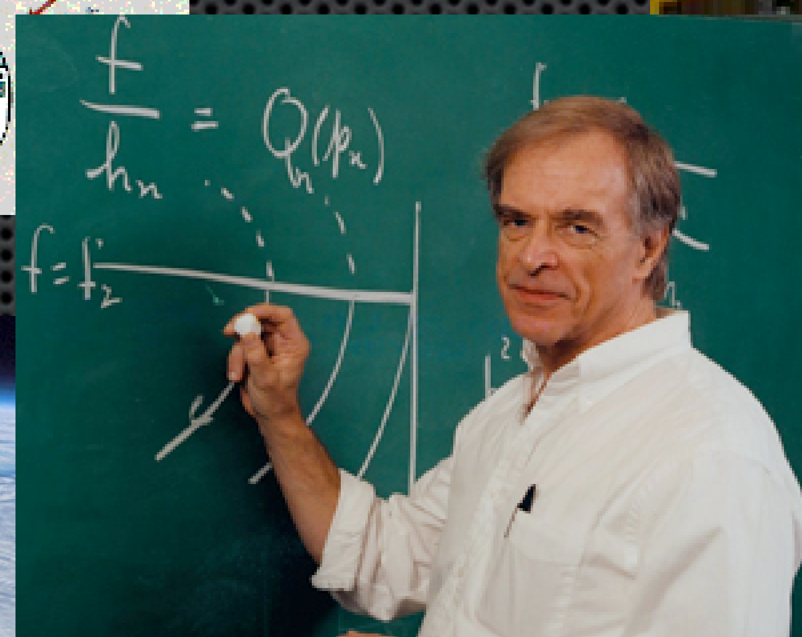

Baylor Fox-Kemper
Pedlosky PhD Student '03
Now at University of Colorado at Boulder

# 21st Century Joe




Baylor Fox-Kemper, Joe’s
only post-millenium PhD graduate

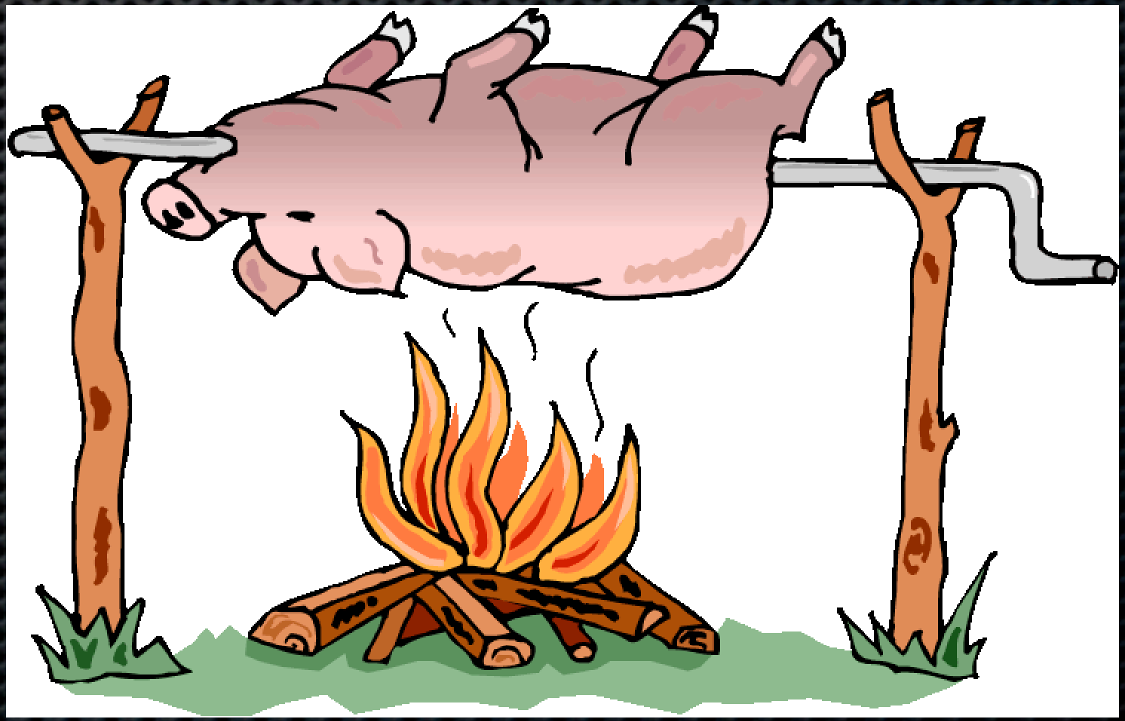




This is my first tribute presentation, so

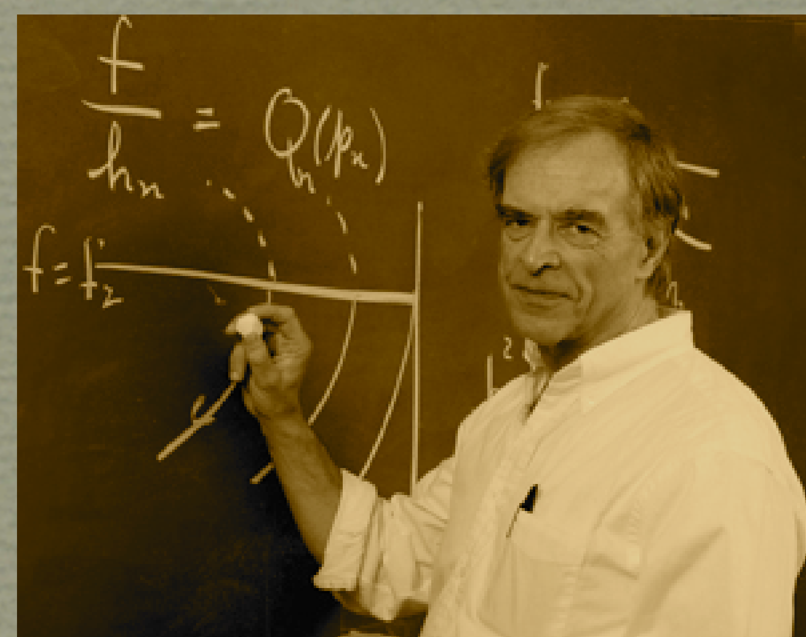
This is my first tribute presentation, so

Or



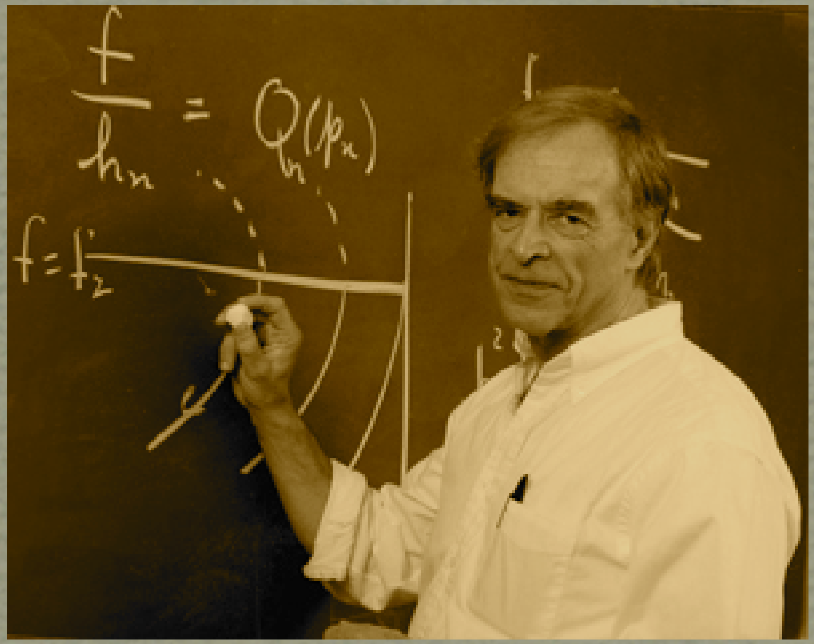
?

# Symposium to Honor
# Joe Pedlosky




Baylor Fox-Kemper, Joe's PhD Student 2003
Now at
University of Colorado-Boulder /CIRES

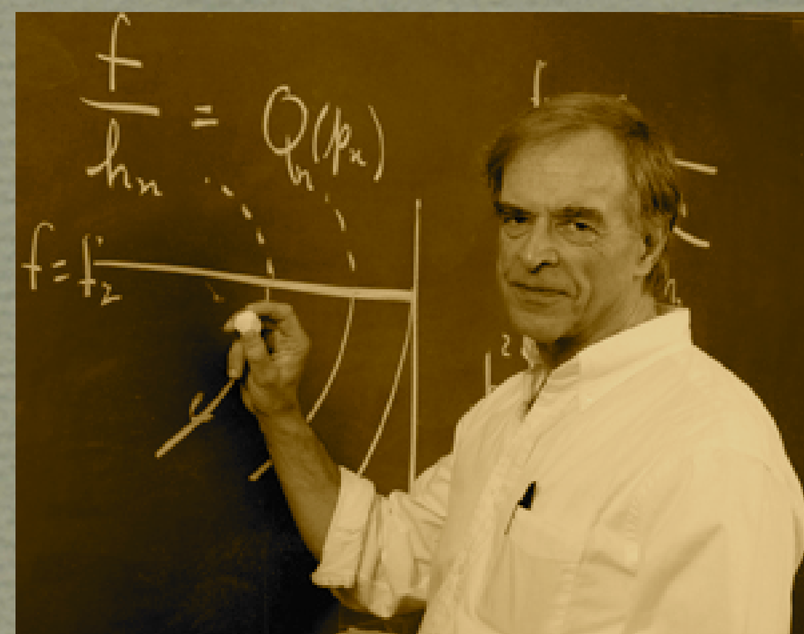
# OK, A Bit Unfair…



BAYLOR FOX-KEMPER, JOE'S PHD STUDENT 2003
NOW AT
UNIVERSITY OF COLORADO-BOULDER /CIRES

# OK, A Bit Unfair...

Atlantis@WHOI
1931-1966

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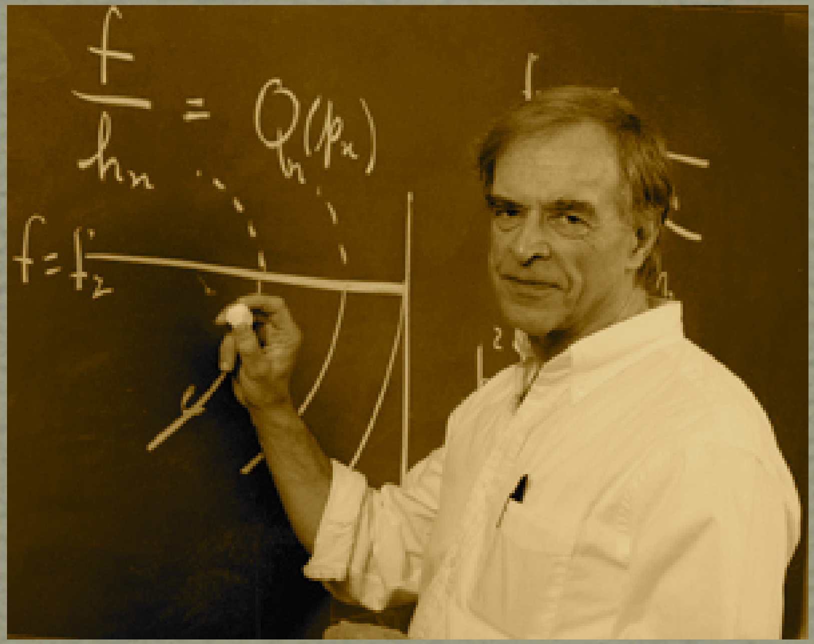
# OK, A Bit Unfair...

Atlantis@WHOI
1931-1966

Joe@WHOI
1977-

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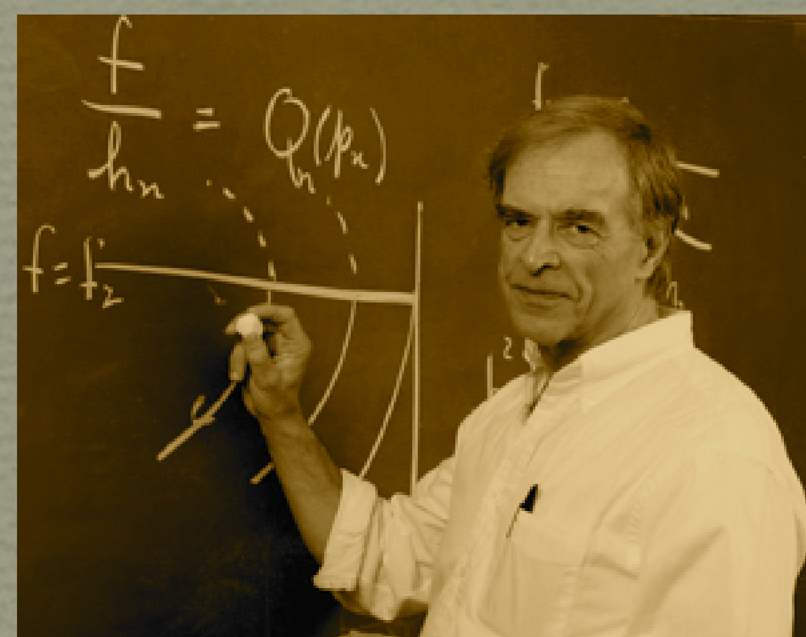
# OK, A Bit Unfair...

Atlantis@WHOI
1931-1966

Joe@GFD Cottage
1960

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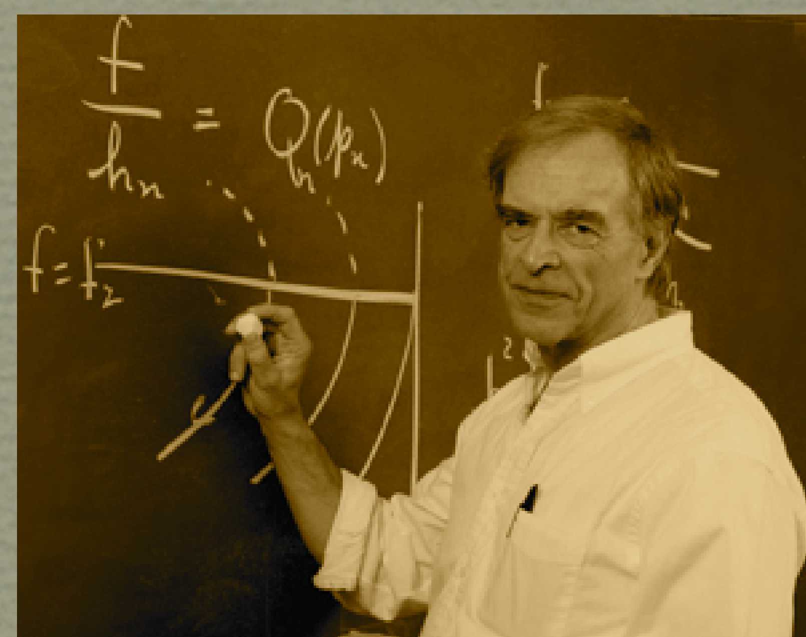


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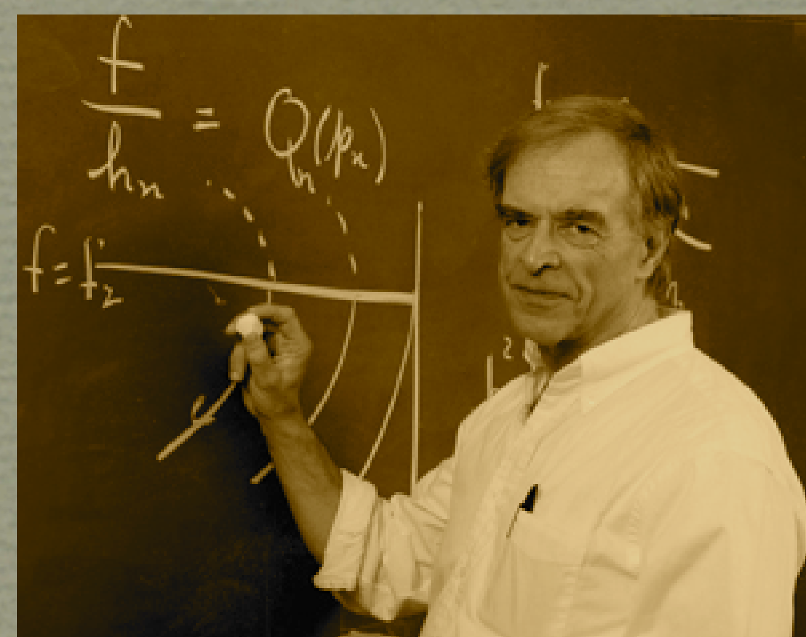


Franklin
1785

BAYLOR FOX-KEMPER, JOE'S PHD STUDENT 2003
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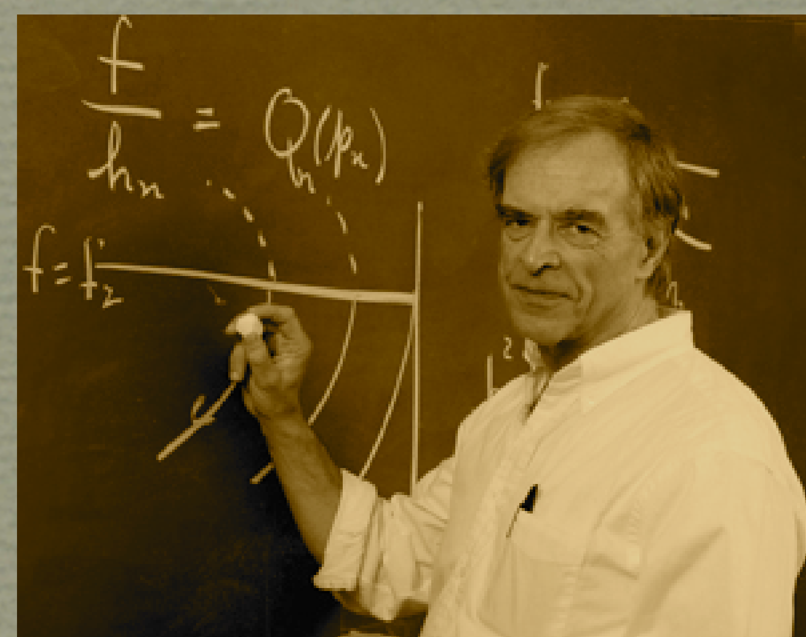
# OK, A Bit Unfair...

Joe on WBC
1965

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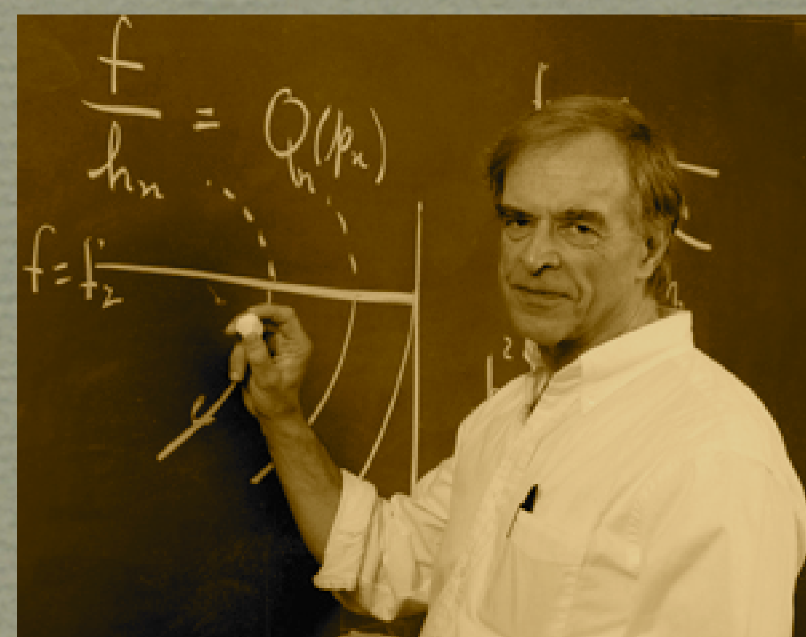

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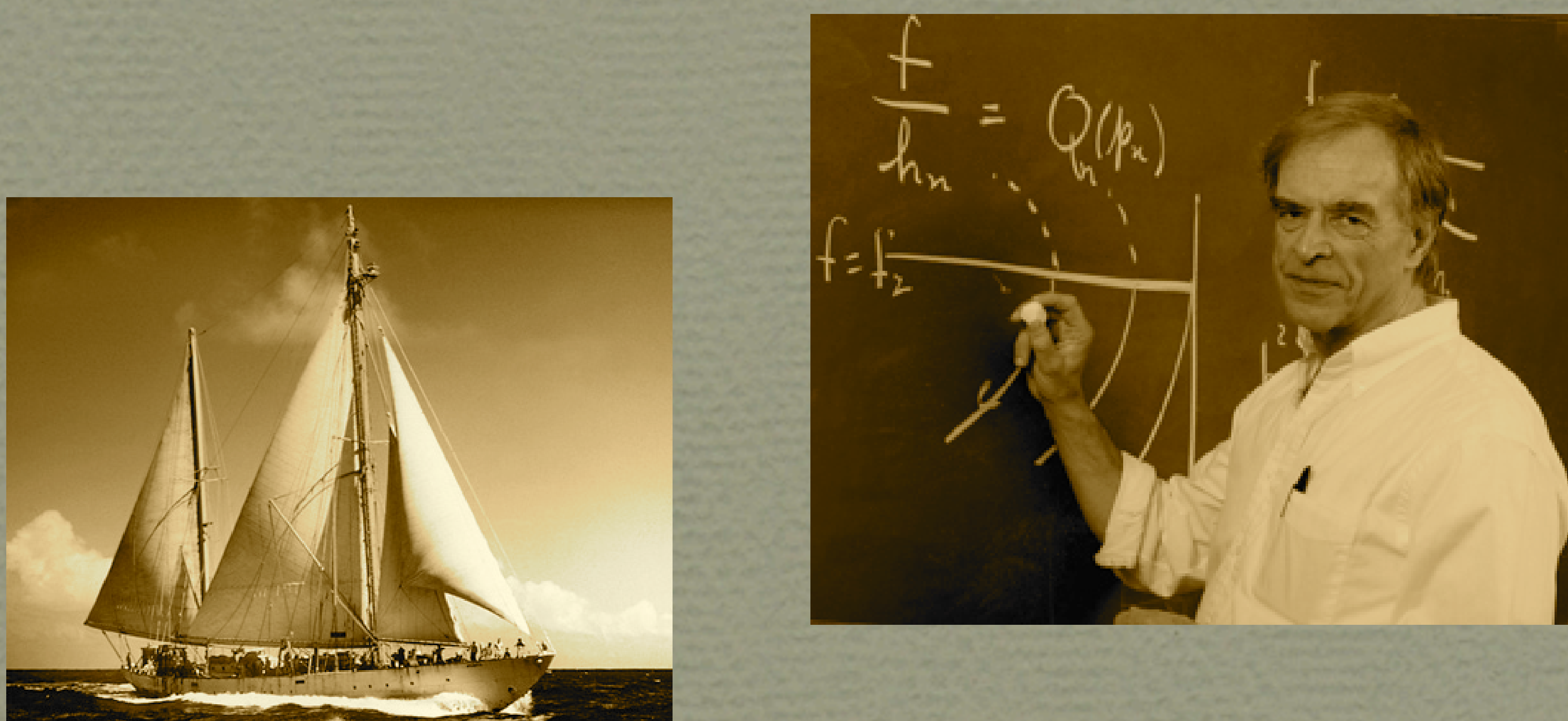

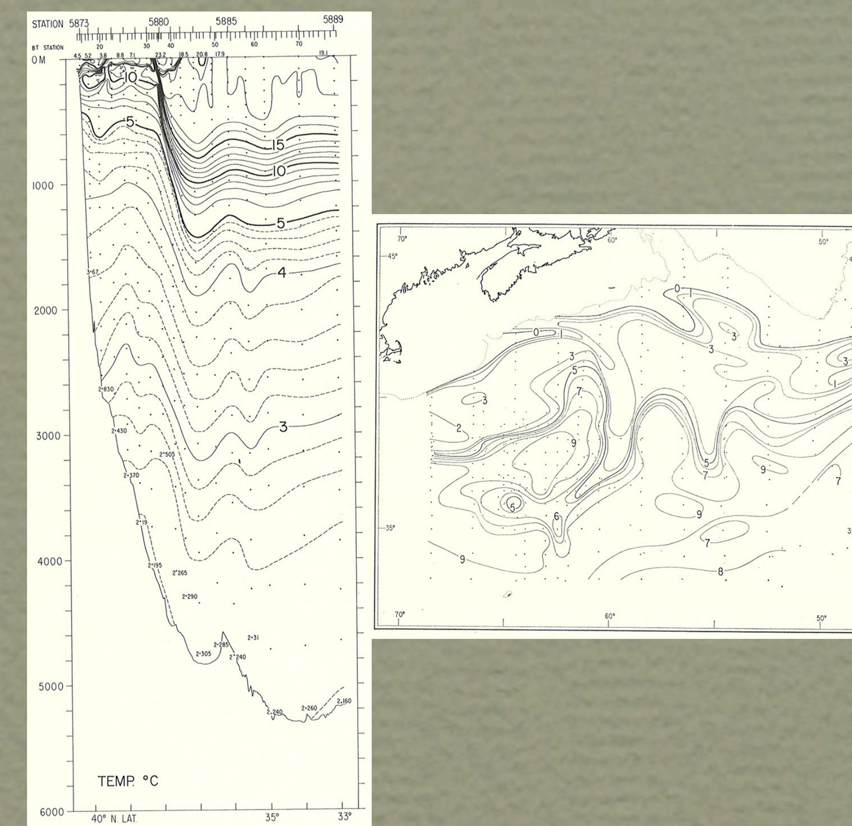


Fuglister
1963

Baylor Fox-Kemper, Joe's PhD Student 2003
Now at
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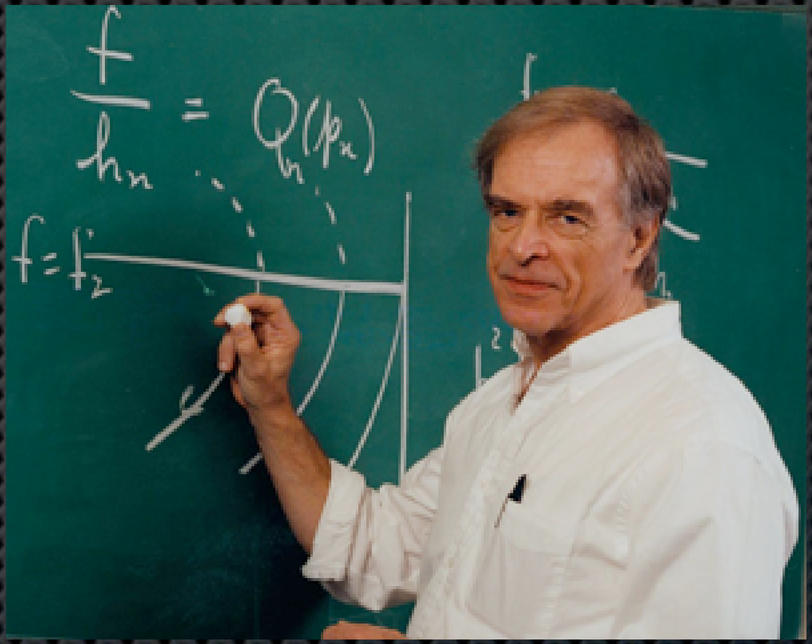
# 21st Century Joe

Joe was so productive working as he did...



Is his style of work still useful in the face of tomorrow's huge datasets & fast computers?

# We don’t need to think, just compute...


- Moore’s Law: Doubling of CPU speed every 1.5 yrs
- Kryder’s Law: Doubling of hard drive density every 1 yr
- Ray Kurzweil predicts that:
  - In 2009, networked clusters will exceed the processing power of the human brain ($2 \times 10^{16}$ flops)
  - By 2020, this processing power will cost only $1000
  - By 2050, $1000 will buy the processing power of all human brains combined

# If we're not clever, what do we brutes need to resolve?

- Mesoscale Eddies (10km):  CPUx1 (teraflops, terabytes, 10MW)
- Submesoscale Eddies (1km): CPUx$10^3$ (petaflops,100MW)
- Langmuir Circulations (10m): CPUx$10^6$ (exaflops, GW???)
- Finescale Turbulence (1m): CPUx$10^9$ (zettaflops)
- Viscous scales (0.01m): CPUx$10^{15}$ ($10^{27}$ flops)
- Salinity diffusion (0.0001m): CPUx$10^{21}$ ($10^{33}$ flops)

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Oschlies 2002: 2km Important!

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  My Brain

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Even Moore doesn't believe
Moore's Law will hold!!! Inquirer (2005)

# Guidance from Joe: Some Examples

- Equilibration of a Damped, Unstable Wave
- Parson’s Model (with R. Ferrari)
- Time-Dependent Ocean

# It’s hard to substitute algorithms for eyes...



## Chaotic and Periodic Behavior of Finite-Amplitude Baroclinic Waves

JOSEPH PEDLOSKY

*Woods Hole Oceanographic Institution, Woods Hole, MA 02543*

CHRISTOPHER FRENZEN

*Applied Mathematics Group, University of Washington, Seattle 98109*

(Manuscript received 12 December 1979, in final form 25 February 1980)

ABSTRACT

Numerical integrations of the amplitude equations governing the dynamics of a weakly unstable finite-amplitude baroclinic wave have revealed a new and unexpectedly complex dependence on the degree of dissipation. We have found for very small dissipation the simple limit cycle behavior noted earlier by Pedlosky (1971) and Smith and Reilly (1977). For *slightly* higher values of the dissipation further solution bifurcations reveal an ever-increasing family of periodic solutions whose periods are even multiples of the fundamental. The critical value of the dissipation parameter $\gamma$ for which the $n$th cycle emerges, appears to satisfy the Feigenbaum (1978) relation $(\gamma_n - \gamma_{n-1})/(\gamma_{n+1} - \gamma_n) = 4.669201$. Above a limit point $\gamma_\infty$ the solutions are aperiodic and chaotic. However, at isolated "islands" within this chaotic regime we have again found periodic solutions. Although their phase plane trajectories differ from those found below $\gamma_\infty$, their periods are always multiples of *half* the fundamental. For higher $\gamma$, equilibration to steady waves occurs.

The present model is *not* spectrally truncated. We conclude that aperiodic, chaotic behavior is a true quality of the dynamics of baroclinic wave-mean flow interaction for a narrow but finite range of dissipation. Aperiodicity is favored when the dissipation time scale is moderately longer than the $e$-folding time scale for linear instability.

# A Simple Wave Problem

- Two Density Layers
- Rotating Infinite Channel
- Quasi-Geostrophic
- Ekman Layers Top & Bottom
- One Wave at a time

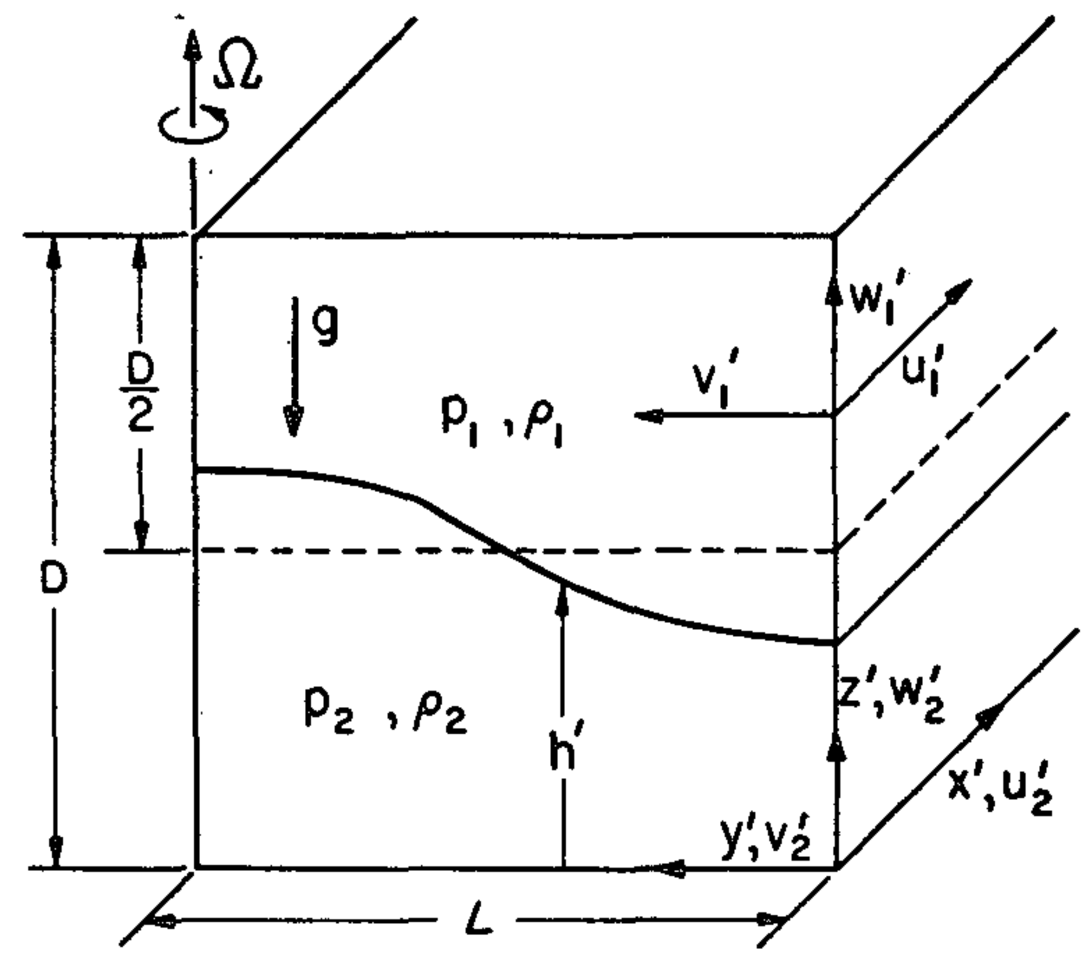



FIG. 1. The two-layer model.



**Finite-Amplitude Baroclinic Waves with Small Dissipation**

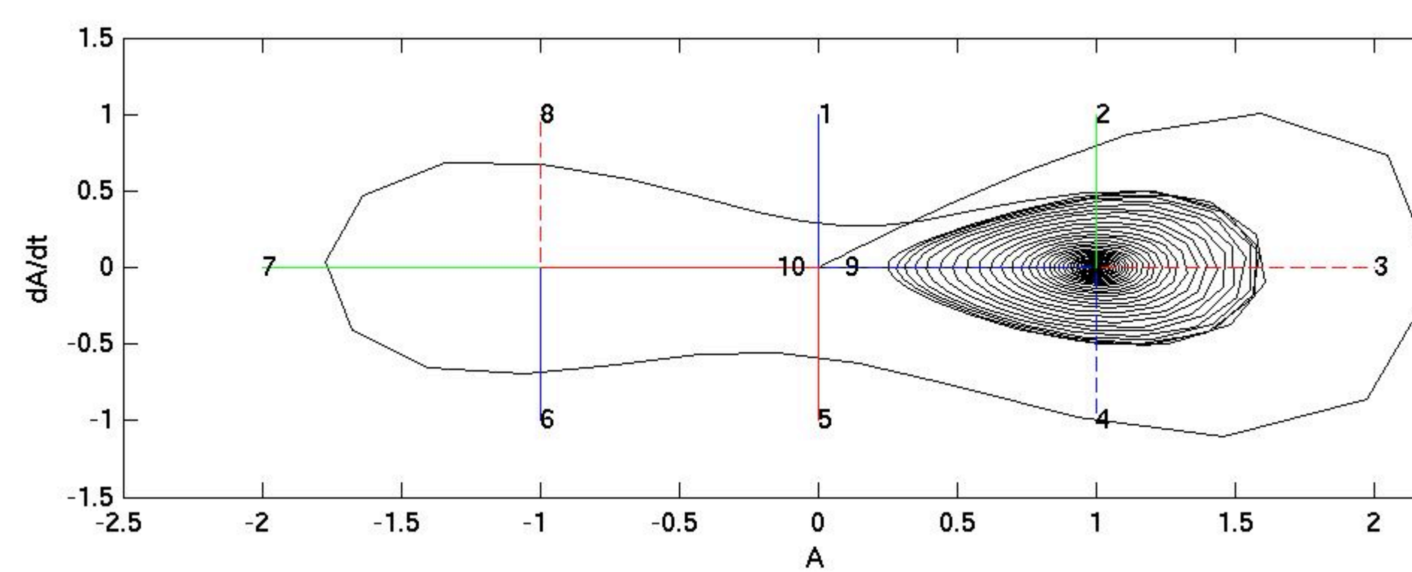

JOSEPH PEDLOSKY

*Dept. of the Geophysical Sciences, The University of Chicago*

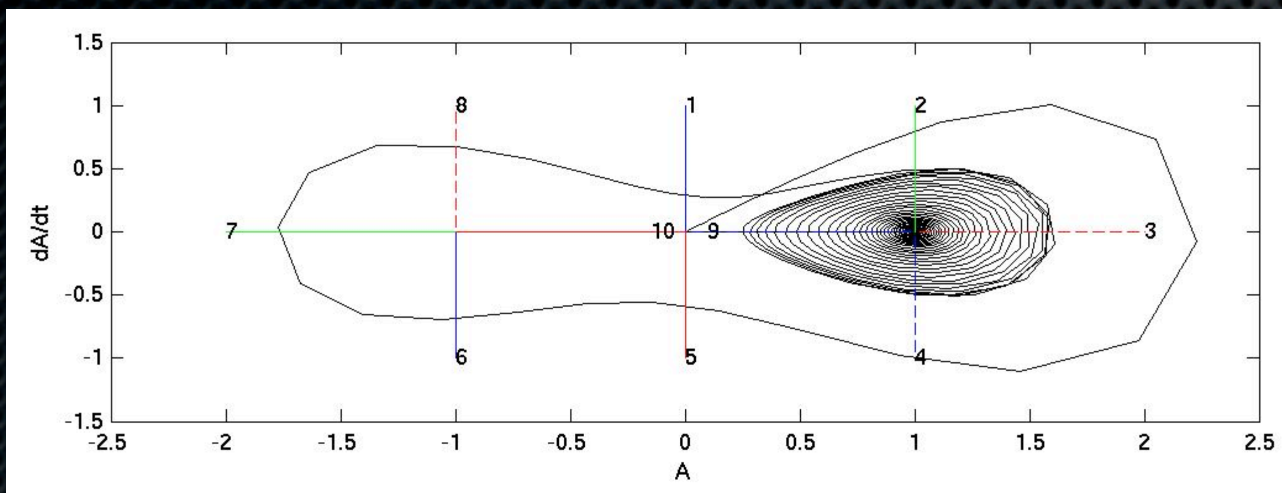

(Manuscript received 26 October 1970)


ABSTRACT

A study of finite-amplitude baroclinic instability for a two-layer system with small but non-zero dissipation is presented. The presence of dissipation, however slight, allows the existence of steady finite-amplitude wave solutions. For sufficiently small friction, however, the steady wave may be unstable if a certain criterion, presented in this paper, is satisfied. Calculations indicate that in such cases a continuous, slow, periodic amplitude pulsation exists which is independent of the initial conditions.

# Not as simple as it seems...



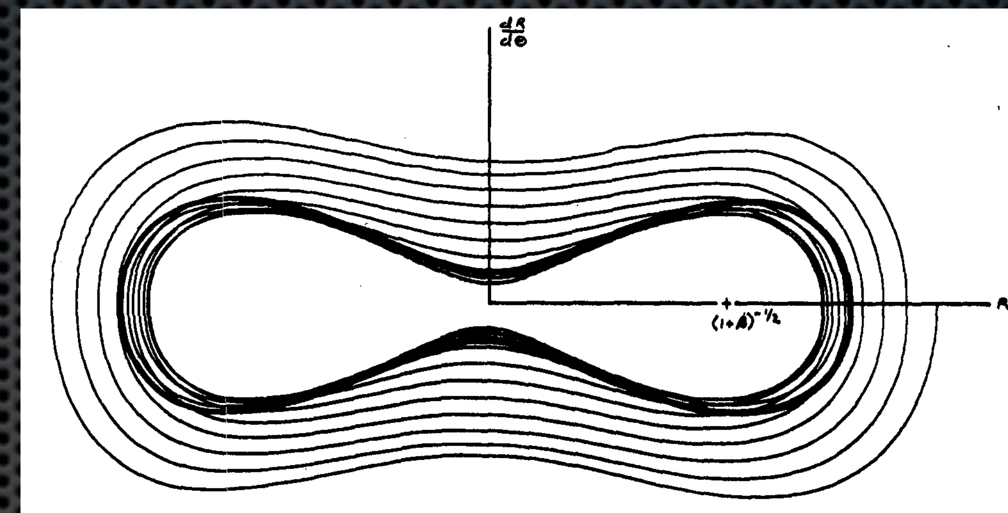




FIG. 2. The "dog-bone" limit cycle found for the set (2.11a,b) for $\eta = 0.01$, $k/m\pi = \sqrt{2}$.

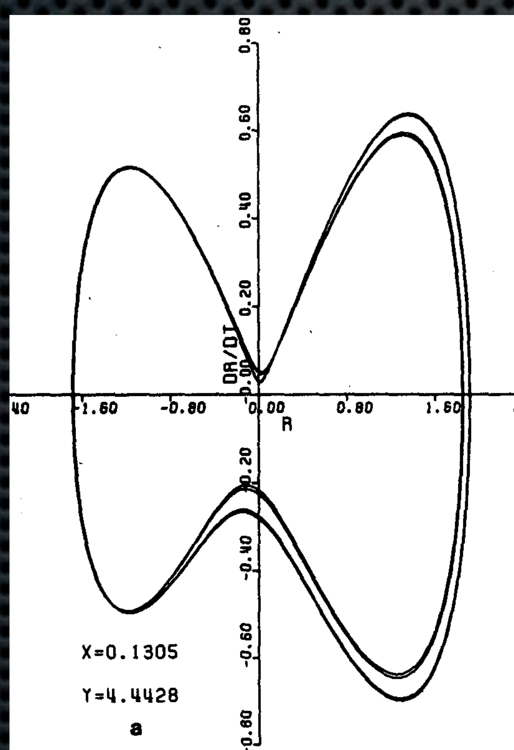
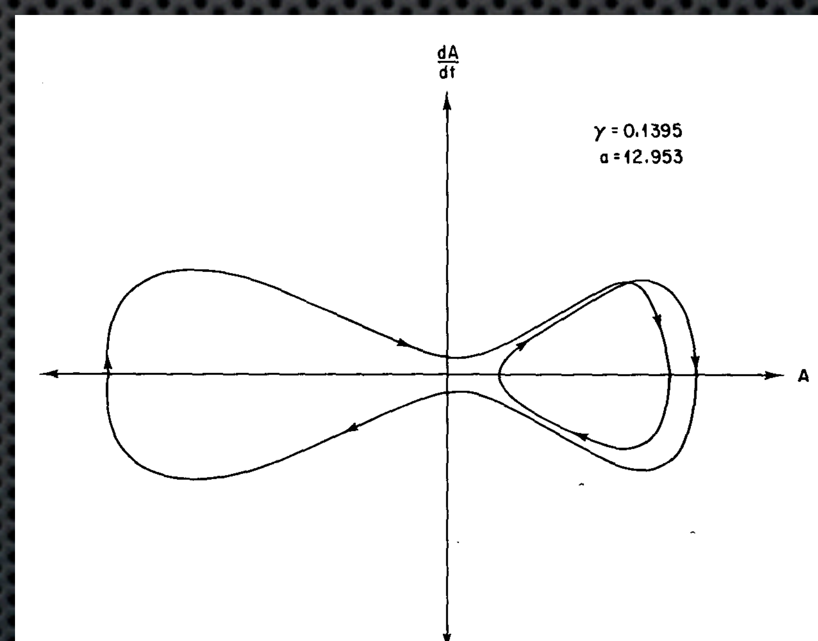



FIG. 7a. As in Fig. 4a except $\gamma = 0.1305$.



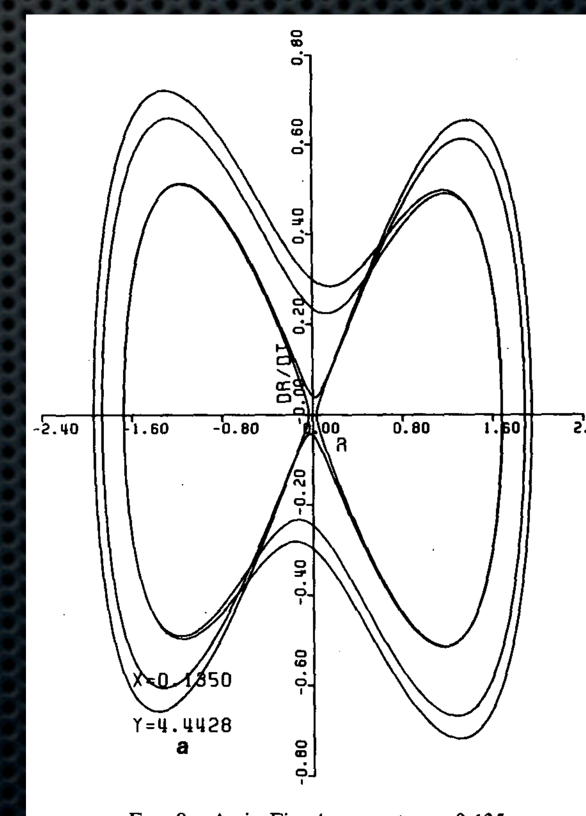
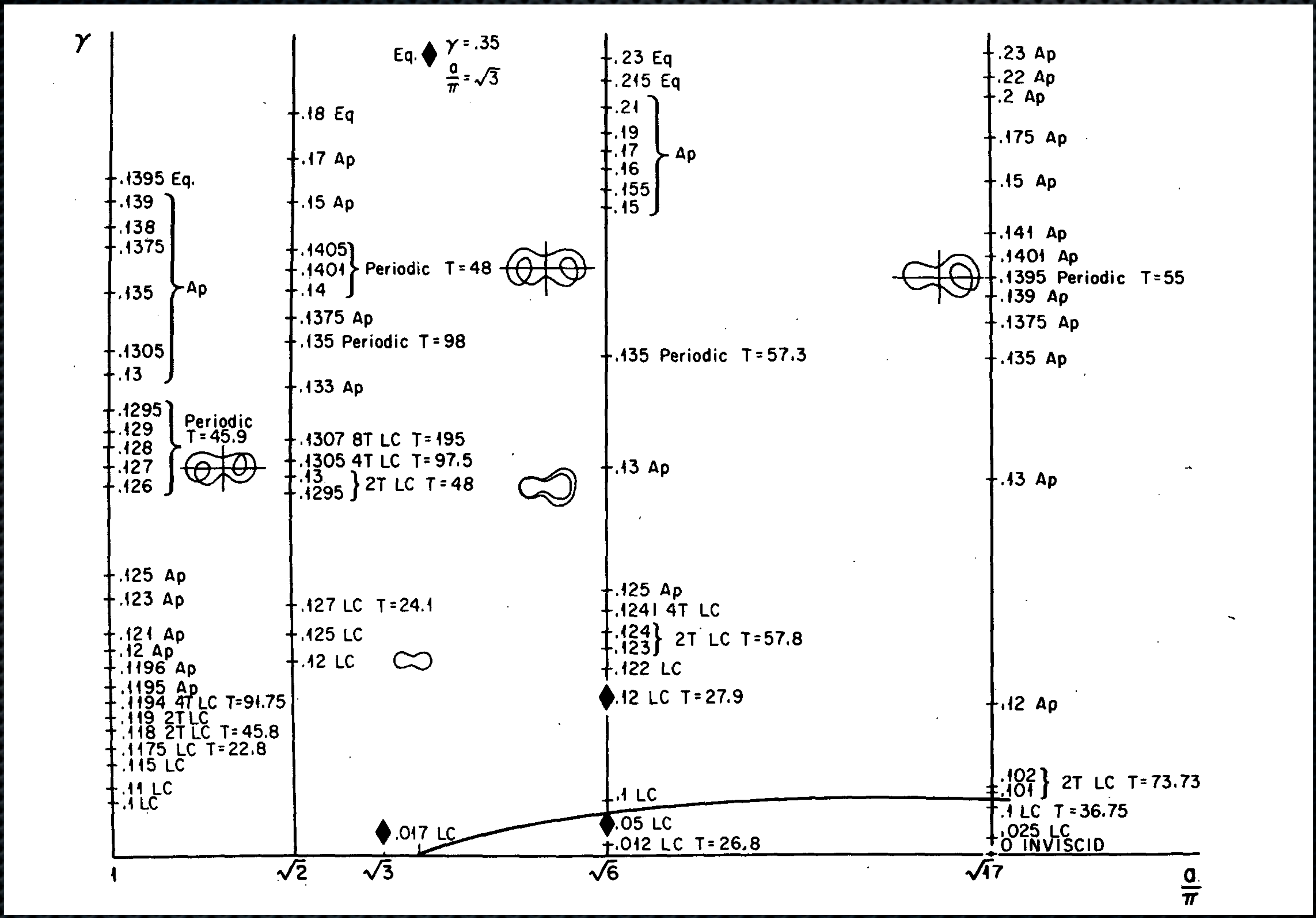



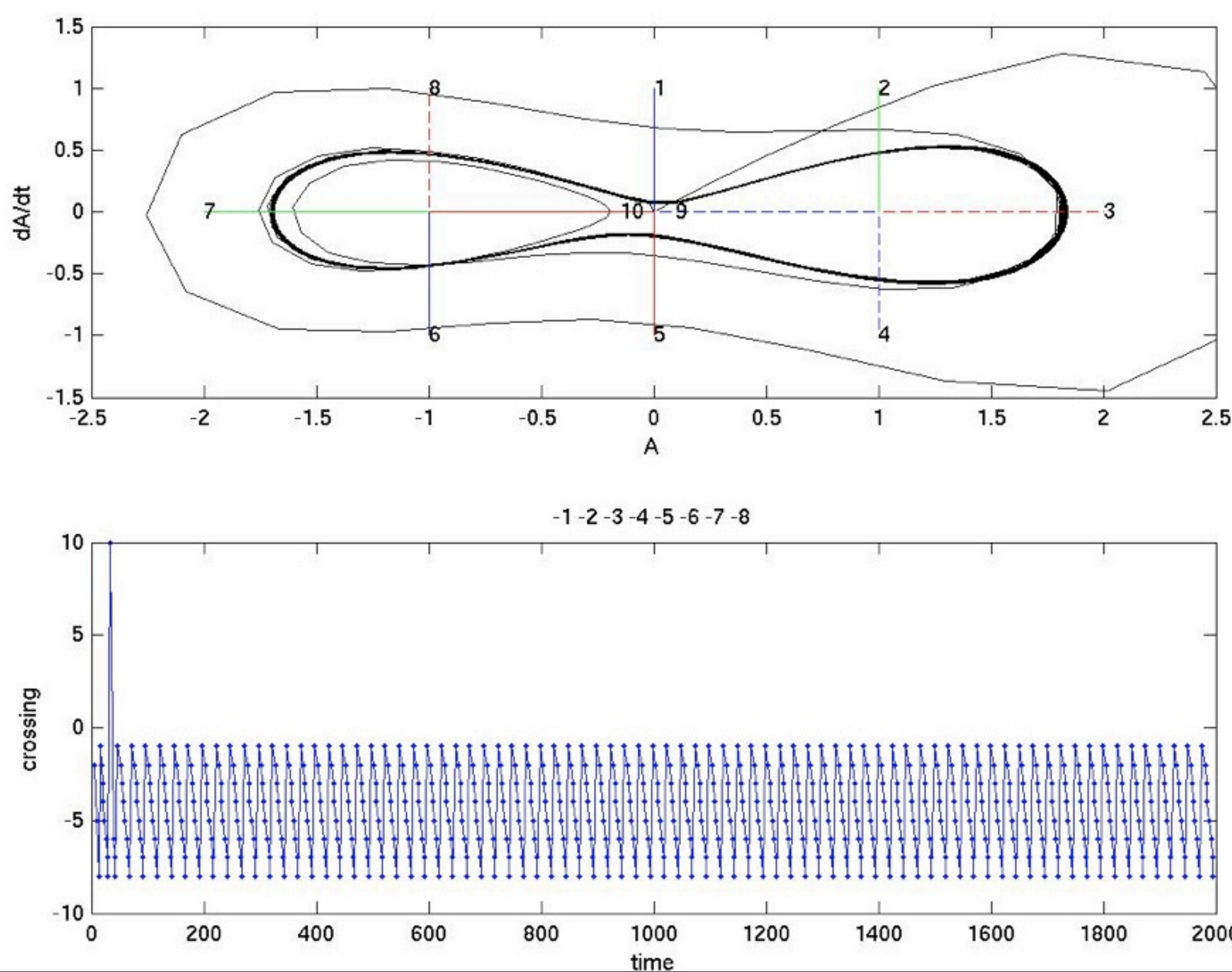

FIG. 9a. As in Fig. 4a except $\gamma = 0.135$.

All of this *before* Mandelbrot's popularity, concurrent with Feigenbaum!

# Pedlosky & Frenzen Summary...

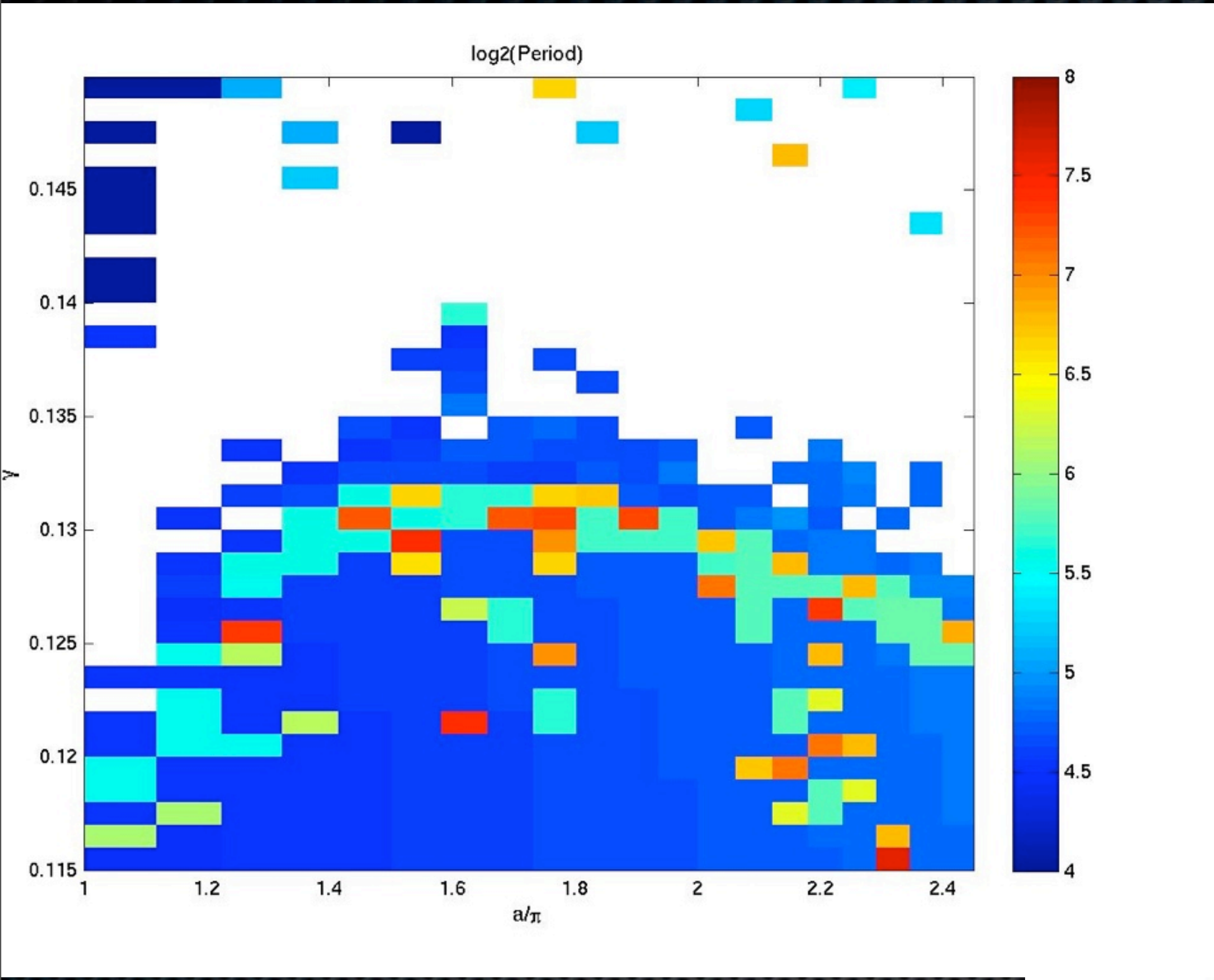


# A New Look...



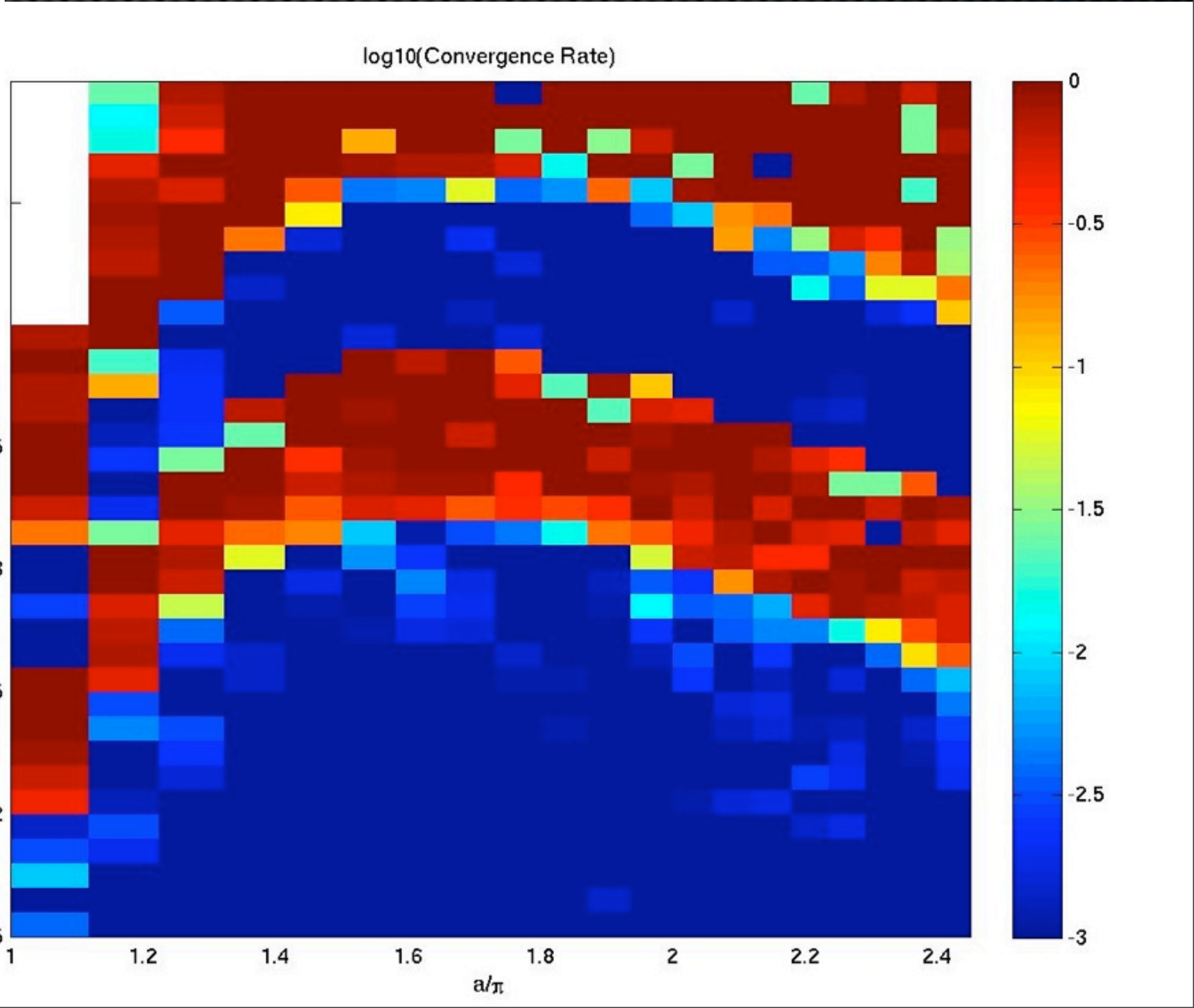
1.5
1
0.5
0
-0.5
-1
-1.5
dA/dt
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
A
1
2
3
4
5
6
7
8
9
10
-1 -2 -3 -4 -5 -6 -7 -8
10
5
0
-5
-10
crossing
0
200
400
600
800
1000
1200
1400
1600
1800
2000
time

# A New Look...




Period

Convergence?



# Know the derivations...
# Massage the definitions...



## On Parsons' Model of the Ocean Circulation*

JOSEPH PEDLOSKY

*Woods Hole Oceanographic Institution, Woods Hole, MA 02543*

(Manuscript received 17 November 1986, in final form 2 April 1987)

ABSTRACT

A model is constructed for the circulation of a combined subtropical and subpolar ocean. The model is similar to that first proposed by Parsons with the important difference that where the isopycnal separating the upper and lower layer outcrops, the Ekman flux is allowed to freely cross the outcrop line instead of being blocked by the isopycnal.

It is shown that this completely alters the global circulation pattern. Outcropping of the cold layer still occurs but along the path described by Luyten, Pedlosky and Stommel, i.e., without an associated separated "Gulf Stream" current.

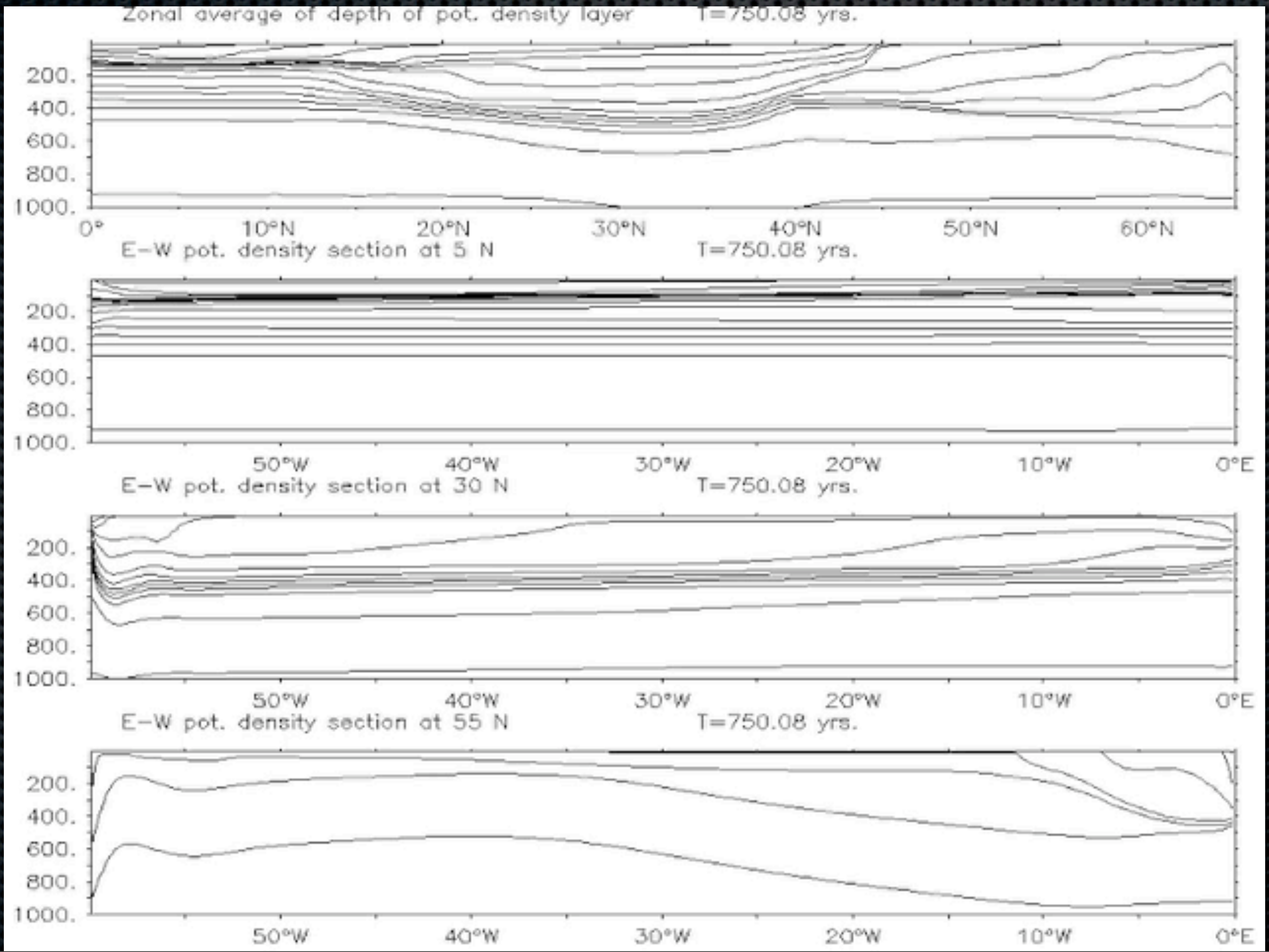
The Ekman flux across the outcrop line implies a water mass conversion which can be calculated directly from the wind stress distribution and is of the order of 5 Sverdrups. This water is allowed to return to the cold water domain along the northern rim and forms a novel branch to the classical Stommel–Arons circulation picture.

A free parameter in this model is the depth of the warm water layer, $H$, on the eastern boundary. However, it is shown that the requirement of continuous solutions requires $H$ to be greater than a critical minimum value which depends only on the reduced gravity $\gamma$, the maximum wind stress $\tau_M$, and the ocean width $x_e$ according to the relation

$$\gamma \frac{H^2}{2} = \tau_M x_e .$$

The nature of the model is then reviewed when a deep upwelling from lower to upper layer is allowed.

# How to burn up CPU-time without getting anywhere...



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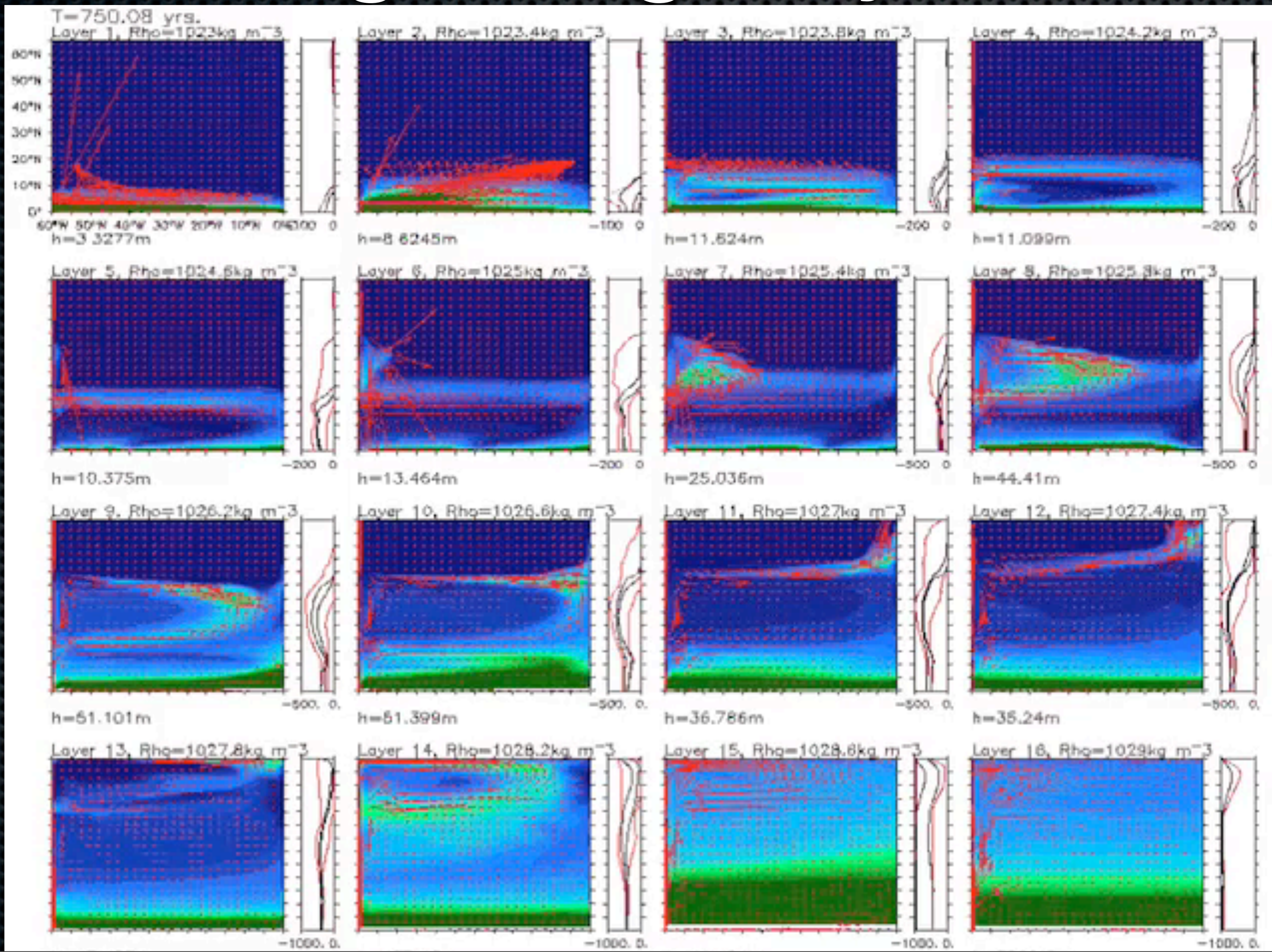

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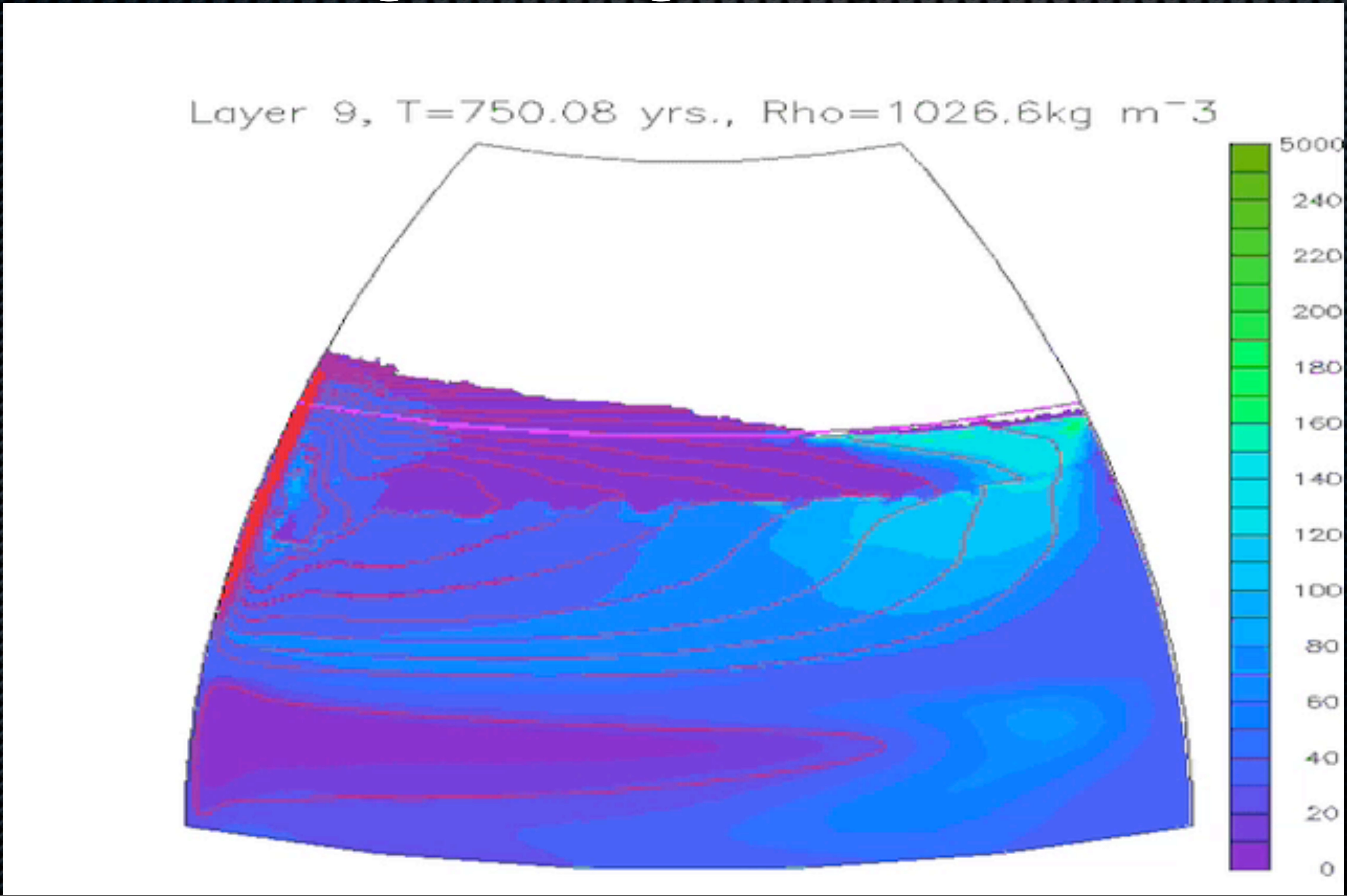
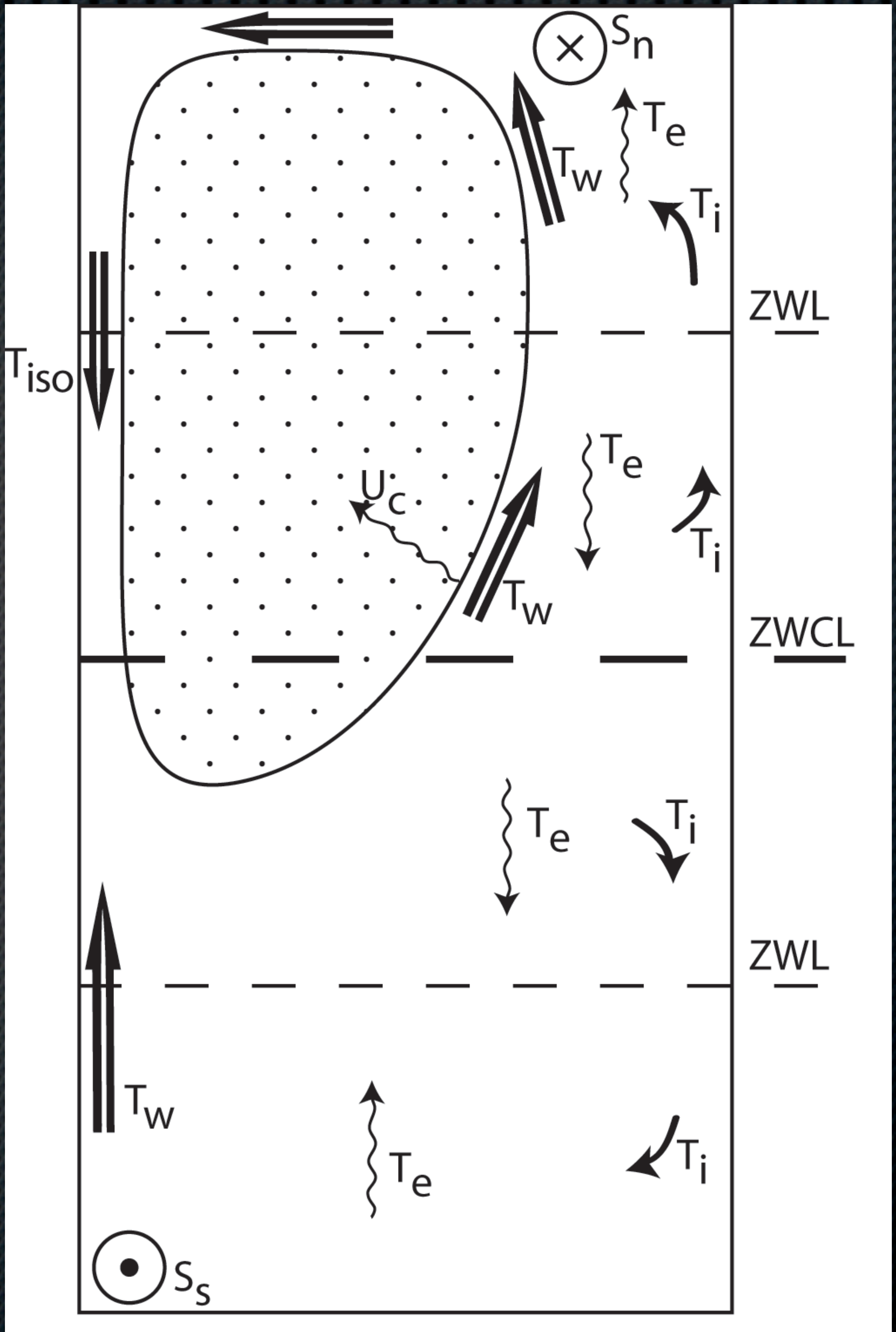


# The Parson's Model

- Two Density Layers
- Nearly Motionless Lower Layer
- Wind-driven
- Add localized cooling/heating
- Steady State
- Requires artificially large friction between layers



# Six of one, a half dozen of the other?

- Consider the continuity, or thickness, equation for an isopycnal-coordinate model:

$$\frac{\partial h}{\partial t} + \nabla \cdot h\mathbf{u} = \mathcal{S}$$

- Parson's model is steady; can we add eddies?
- We can average like this,

$$\nabla \cdot \overline{h}\overline{\mathbf{u}} = -\nabla \cdot \overline{h'\mathbf{u}'} + \overline{\mathcal{S}}$$

- Or, we could use the thickness-weighted average:

$$\nabla \cdot \overline{h}\overline{\mathbf{u}}^{\dagger} = \overline{\mathcal{S}} \qquad \overline{\mathbf{u}}^{\dagger} \equiv \frac{\overline{h\mathbf{u}}}{\overline{h}}$$

# Redefining the mean, it's easy!

- The Parson's Model is readily adapted to solve for a thickness-weighted mean instead of a steady solution.
- The outcrop location, boundary current transport, double-gyre solutions (Huang & Flierl), even diabatic and surface forcing and mixed layer effects (Pedlosky, Veronis, Nurser and Williams) carry through nearly effortlessly.
- Constraints (Sverdrup, Fox-Kemper & Pedlosky) readily generalize, so long as eddies behave nicely.

# Results in a Bdy Layer Width

- The upper layer of the thickness-weighted Parson's model can be nearly inviscid (the eddy fluxes transport momentum down where bottom drag can get it)
- If so, the boundary layer width is close to an eddy mixing length, if the typical eddy velocity is taken to be the long Rossby wave speed.

$$\delta_b = \frac{\kappa_1}{c_R} \, \frac{\mathbf{A}_{nn}}{\hat{\mathbf{s}} \cdot \hat{\mathbf{y}}}.$$

# What do we know about the Eulerian mean velocity anyhow?

- We rarely observe the mean flow directly.
- We sometimes observe snapshots of the flow directly.
- We usually infer the mean flow corresponding to our snapshots from the location of tracers, but tracers are advected by the thickness-weighted mean anyway!

# Sometimes you already know everything you need...



## A Study of the Time Dependent Ocean Circulation[1]

Joseph Pedlosky

*Massachusetts Institute of Technology, Cambridge, Mass.*

(Manuscript received 2 September 1964, in revised form 18 November 1964)

ABSTRACT

The response of a simple bounded-ocean model to a fluctuating wind stress is studied. Both the linear response and the resulting steady non-linear circulations are computed. The results of this analysis show that the structures of the steady and fluctuating ocean circulations are strongly dependent on the frequency of the forcing.

# A complete set...

Journal of the Oceanographical Society of Japan
Vol. 43, pp. 237 to 243, 1987

## A Proof and Applications of the Expansion Theorem for the Rossby Normal Modes in a Closed Rectangular Basin*

Akira Masuda†

**Abstract**: An expansion theorem is derived for Rossby normal modes in a closed rectangular basin and the set of Rossby normal modes is proved to be complete. This theorem provides a general linear solution to the initial value problem as well as to the response problem. In particular, the Green's function is obtained for the instantaneous localized torque anywhere in the basin. Weakly nonlinear versions are solved also by the combination of the general linear solution with the asymptotic expansion in terms of small amplitude. Further, an application is suggested to the spectral method of numerical simulation based on Rossby normal modes relevant to the more nonlinear evolution equation on a $\beta$-plane, instead of *sin* functions or Chebyshev polynomials, which have been employed conventionally for this purpose.

# With fascinating implications...

## Statistical Mechanics for Truncations of the Burgers-Hopf Equation: A Model for Intrinsic Stochastic Behavior with Scaling

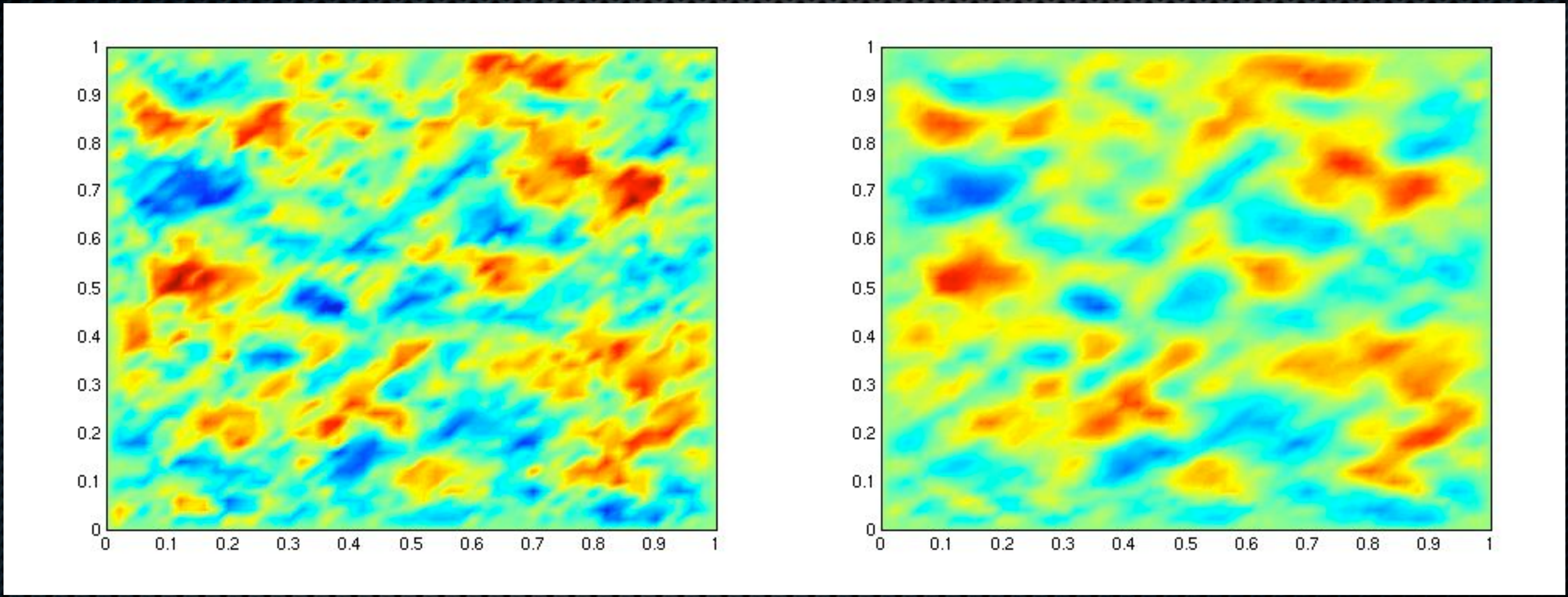
A. Majda and I. Timofeyev

**Abstract.** In this paper we consider both analytically and numerically several finite-dimensional approximations for the inviscid Burgers-Hopf equation. Fourier Galerkin truncation is introduced and studied as a simple one-dimensional model with intrinsic chaos and a well-defined mathematical structure allowing for an equilibrium statistical mechanics formalism. A simple scaling theory for correlations is developed that is supported strongly by the numerical evidence. Several semi-discrete difference schemes with similar mathematical properties conserving discrete momentum and energy are also considered. The mathematical properties of the difference schemes are analyzed and the behavior of the difference schemes is compared and contrasted with the Fourier Galerkin truncation. Numerical simulations are presented which show similarities and subtle differences between different finite-dimensional approximations both in the deterministic and stochastic regimes with many degrees of freedom.

# Tricky, though...

Original Signal

Basin Mode Rep.

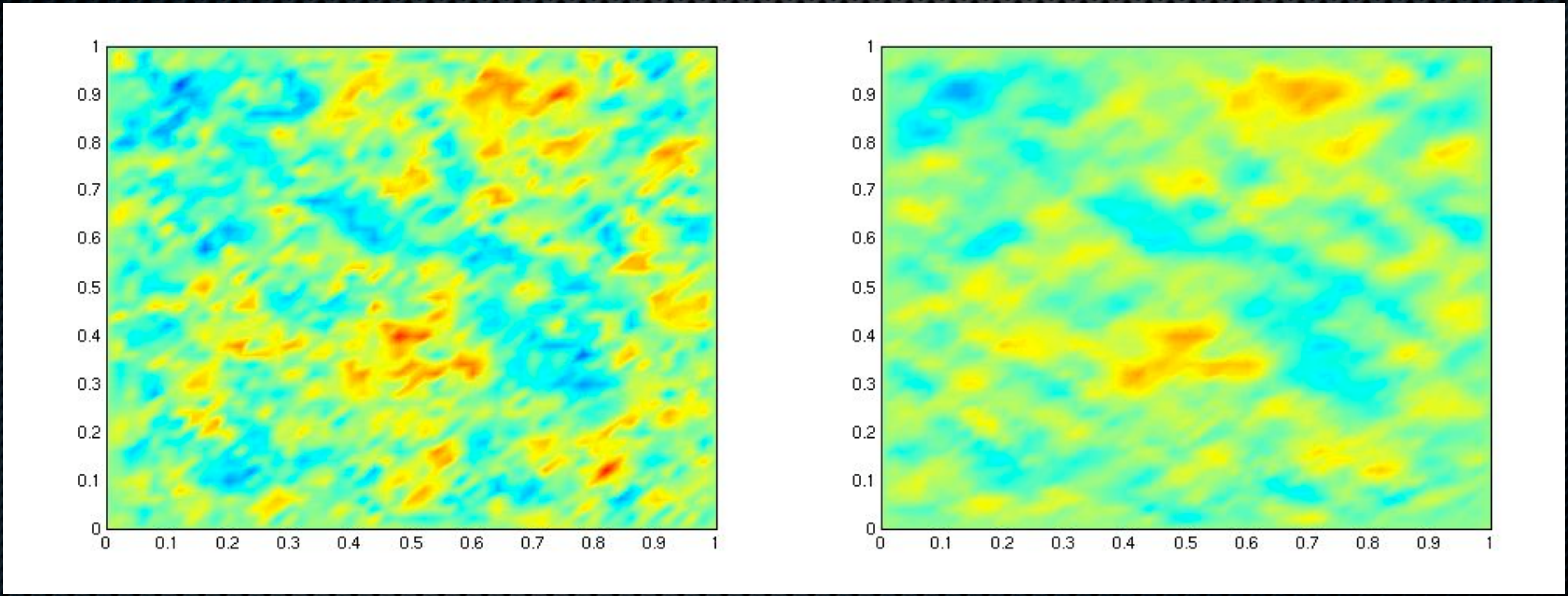



Little Noise

# Tricky, though...

Original Signal

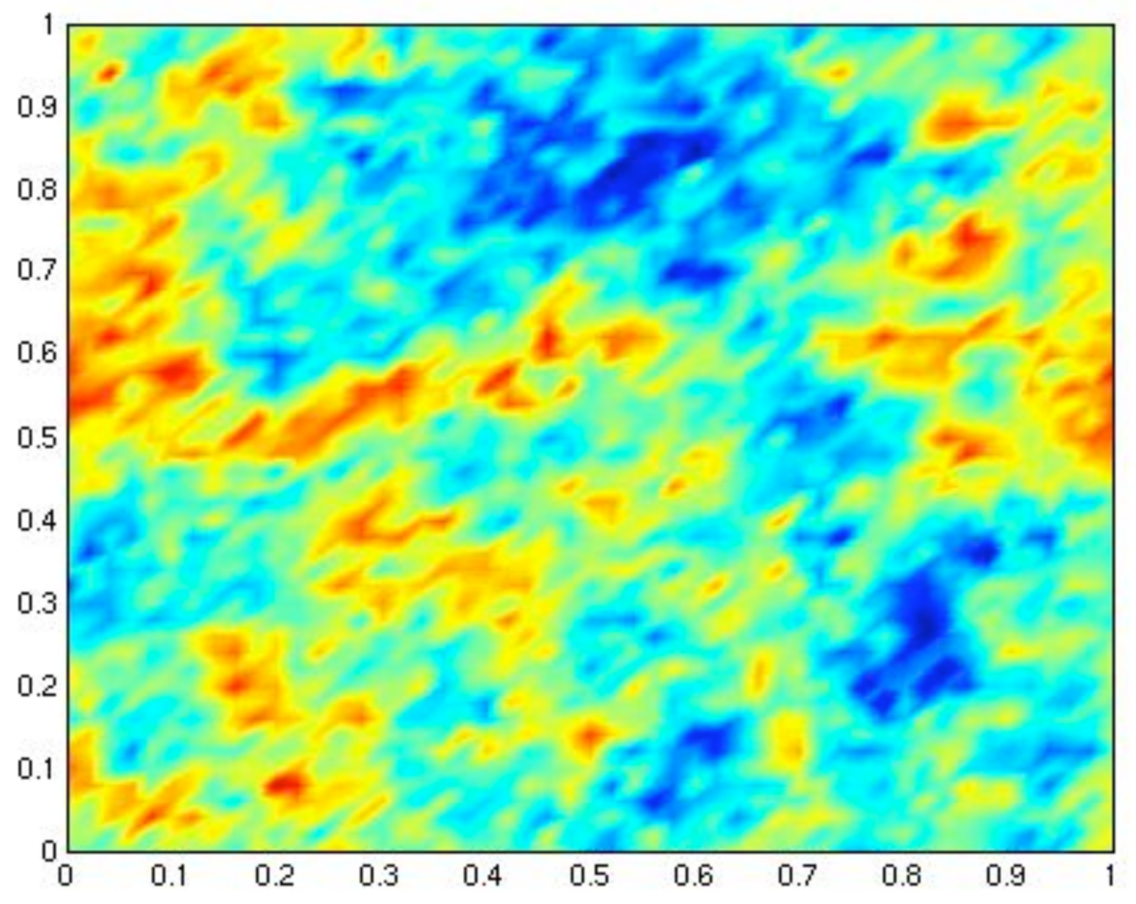
Basin Mode Rep.



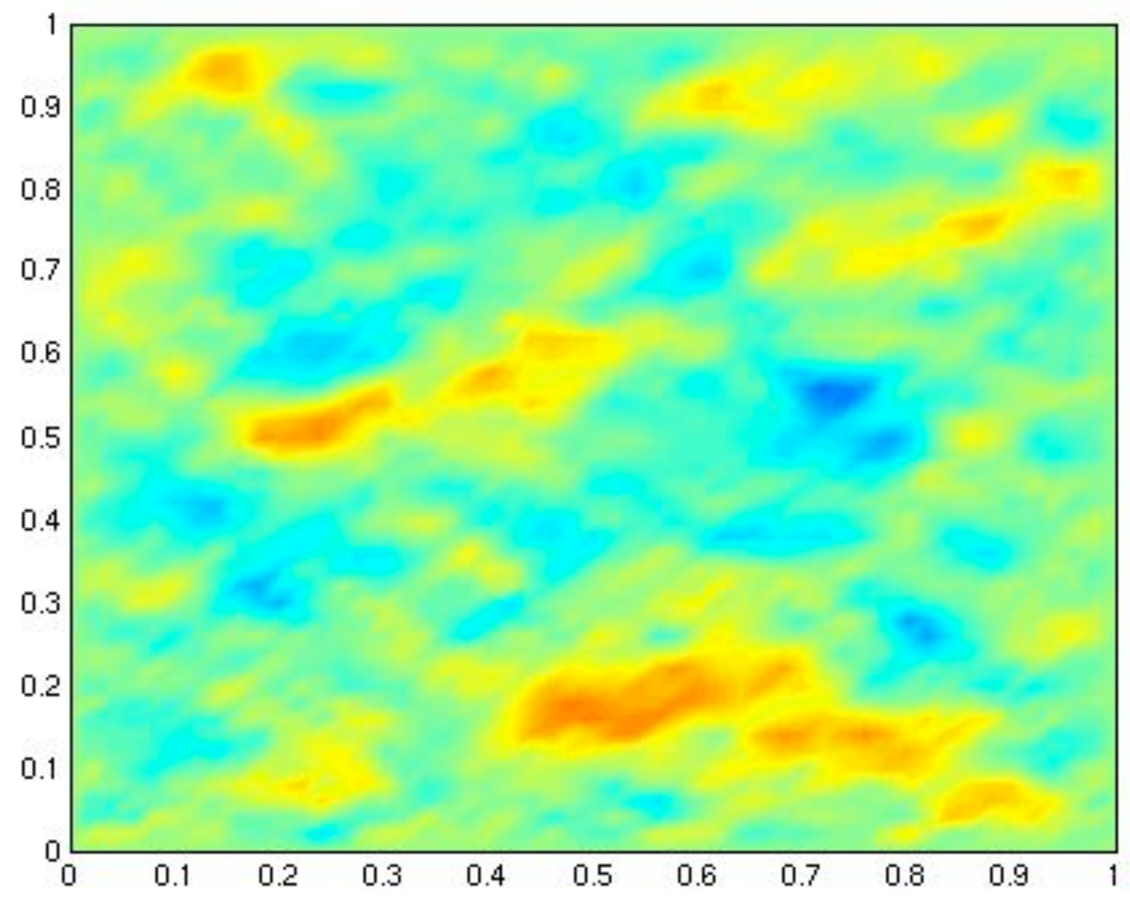

More Noise

# Tricky, though...

Original Signal




Basin Mode Rep.




Strong Noise

# To Conclude

- The insights of human scientists will not be replaced by machines anytime soon...
- Joe will not be replaced by man or machine...